16 RISK, TOXICOLOGY, AND HUMAN HEALTH

The Big Killer

What is roughly the diameter of a 30-caliber bullet, can be bought almost anywhere, is highly addictive, and kills about 11,000 people every day, or 460 per hour? It's a cigarette. *Cigarette smoking is the single most preventable major cause of death and suffering among adults.*

The World Health Organization (WHO) estimates that each year tobacco contributes to the premature deaths of at least 4 million people from heart disease, lung cancer, other cancers, bronchitis, emphysema, and stroke. The annual death toll from smoking-related diseases is projected to reach 10 million by 2030 (70% of them in developing countries)—an average of about 27,400 preventable deaths per day. In China alone, health experts project that 2 billion people will die prematurely each year from tobacco-related causes by 2020.

Smoking kills about 431,000 Americans per year, an average of 1,180 deaths per day (Figure 16-1). This death toll is roughly equivalent to three fully loaded jumbo (400-passenger) jets crashing every day with no survivors. Smoking causes more deaths each year in the United States than do all illegal drugs, alcohol (the second most harmful legal drug after nicotine), automobile accidents, suicide, and homicide combined (Figure 16-1).

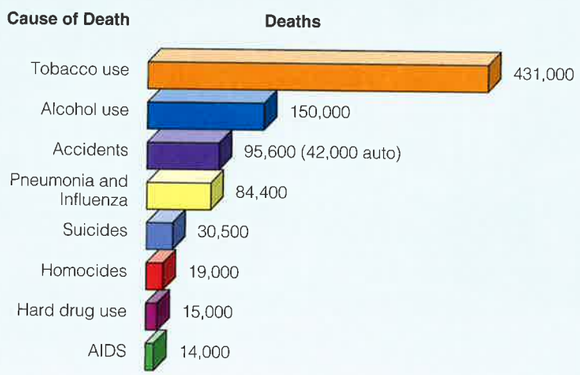

Figure 16-1 Annual deaths in the United States from tobacco use and other causes. Smoking is by far the nation's leading cause of preventable death, causing more premature deaths each year than all the other categories in this figure combined. (Data from National Center for Health Statistics)

According to a 1998 study, secondhand smoke (inhaled by nonsmokers) causes 30,000–60,000 premature deaths per year in the United States. Each year, parental smoking prematurely kills an estimated 6,000 children and causes 5.4 million serious child ailments in the United States.

The overwhelming consensus in the scientific community is that the nicotine (and probably the acetaldehyde) inhaled in tobacco smoke is highly addictive. Only 1 in 10 people who try to quit smoking succeed—about the same relapse rate as for recovering alcoholics and those addicted to heroin or crack cocaine. A British government study showed that adolescents who smoke more than one cigarette have an 85% chance of becoming smokers.

Worldwide, the cost of treating smoking-related illnesses is estimated at $200 billion a year, and in the United States $70–100 billion a year is spent on **(1)** medical bills, **(2)** increased insurance costs, **(3)** disability, **(4)** lost earnings and productivity because of illness, and **(5)** property damage from smoking-caused fires. This is an average of $3–4 per pack of cigarettes sold in the United States.

Many health experts urge that a $2–4 federal tax be added to the price of a pack of cigarettes in the United States. In England a pack of cigarettes costs about $5, versus $2 in the United States. Such a tax would mean that the users of cigarettes (and other tobacco products), not the rest of society, would pay a much greater share of the health, economic, and social costs associated with their smoking: a *user-pays* approach.

Other suggestions for reducing the death toll and health effects of smoking in the United States include **(1)** banning all cigarette advertising, **(2)** forbidding the sale of cigarettes and other tobacco products to anyone under 21 (with strict penalties for violators), **(3)** banning all cigarette vending machines, **(4)** classifying nicotine as an addictive and dangerous drug (and placing its use in tobacco or other products under the jurisdiction of the Food and Drug Administration), **(5)** eliminating all federal subsidies and tax breaks to U.S. tobacco farmers and tobacco companies, and **(6)** using cigarette tax income to finance a massive antitobacco advertising and education program.

The dose makes the poison.
PARACELSUS, 1540

This chapter addresses the following questions:

- What types of hazards do people face?
- What is toxicology, and how do scientists measure toxicity?
- What chemical hazards do people face, and how can they be measured?
- What types of disease (biological hazards) threaten people in developing countries and developed countries?
- How can risks be estimated, managed, and reduced?

16-1 RISK, PROBABILITY, AND HAZARDS

What Is Risk? **Risk** is the possibility of suffering harm from a hazard that can cause injury, disease, economic loss, or environmental damage. Risk is expressed in terms of **probability**: a mathematical statement about how likely it is that some event or effect will occur. In these terms, **risk** is defined as the probability of exposure times the probability of harm (Risk = Exposure × Harm).

Probability often is stated in terms such as "The lifetime probability of developing cancer from exposure to a certain chemical is 1 in 1 million." This means that one of every 1 million people exposed to the chemical at a specified average daily dosage will develop cancer over a typical lifetime (usually considered to be 70 years).

It is important to distinguish between *possibility* and *probability*. Saying that an event or effect is possible means that it could occur—a very inexact statement. Probability describes in mathematical terms how likely it is that the possible event or effect will occur and how likely it is to cause harm.

How Are Risks Assessed and Managed? Nothing we do is completely safe or entirely free from potential harm. Thus, individuals and government regulators have to assess the risk from a particular hazard to determine whether there is a *low risk* or a *high risk* of harm.

Risk assessment involves **(1)** identifying a real or potential hazard ("What is the hazard?"), **(2)** determining the probability of its occurrence ("How likely is the event?"), and **(3)** assessing the severity of its health, environmental, economic, and social impact ("How much damage is it likely to cause?"; Figure 16-2).

Figure 16-2 Risk assessment and risk management. These are important, difficult, and controversial processes.

This is a complex, difficult, and controversial process. For example, assessing the risk of exposure to a toxic chemical involves estimating **(1)** the number of people or other organisms exposed, **(2)** the level and duration of exposure, and **(3)** other possible contributing factors such as age, health, sex, personal habits, and interactions with other chemicals.

After a risk has been assessed, the next step is **risk management**, in which people make decisions about **(1)** how serious it is compared to other risks (*comparative risk analysis*), **(2)** how much (if at all) the risk should be reduced, **(3)** how such risk reduction can be accomplished, and **(4)** how much money should be devoted to reducing the risk to an acceptable level (Figure 16-2). This is even more difficult and controversial than risk assessment because of a lack of information and the economic, health, and political implications of such decisions.

What Are the Major Types of Hazards? The various kinds of hazards we face can be categorized as follows:

- *Cultural hazards* such as unsafe working conditions, smoking (left), poor diet, drugs, drinking, driving, criminal assault, unsafe sex, and poverty. Some *good news* is that between 1900 and 2000, deaths from industrial accidents in the United States decreased from about 35,000 per year to 6,100 per year despite an almost fourfold increase in population.
- *Chemical hazards* from harmful chemicals in the air (Chapter 17), water (Chapter 19), soil (p. 227), and food (p. 271). The bodies of most human beings contain small amounts of about 500 synthetic organic chemicals—whose health effects are mostly unknown—that did not exist in 1920.

- *Physical hazards* such as ionizing radiation (p. 62), fire, earthquake (p. 217), volcanic eruption (p. 218), flood (p. 314), tornadoes, and hurricanes.
- *Biological hazards* from pathogens (bacteria, viruses, and parasites), pollen and other allergens, and animals such as bees and poisonous snakes.

According to a 1998 study by Cornell University scientist David Pimentel (Guest Essay, p. 232), environmental factors such as malnutrition, smoking, cooking fires, skin cancer, exposures to pesticides and other hazardous chemicals, and air and water pollution contribute to about 40% of the world's annual deaths.

16-2 TOXICOLOGY

What Determines Whether a Chemical Is Harmful? Dose and Response **Toxicity** is a measure of how harmful a substance is. Whether a chemical (or other agent such as ionizing radiation) is harmful depends on several factors. One is the **dosage**, the amount of a potentially harmful substance that a person has ingested, inhaled, or absorbed through the skin. Whether a chemical is harmful depends on **(1)** the size of the dosage over a certain period of time, **(2)** how often an exposure occurs, **(3)** who is exposed (adult or child, for example), **(4)** how well the body's detoxification systems (liver, lungs, and kidneys) work, and **(5)** genetic makeup that determines an individual's sensitivity to a particular toxin (Figure 16-3).

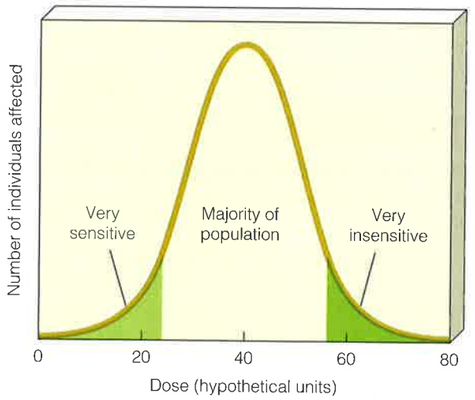

Figure 16-3 Typical variations in sensitivity to a toxic chemical within a population, mostly because of differences in genetic makeup. Some individuals in a population are very sensitive to small does of a toxin (left), and others are very insensitive (right). Most people fall between these two extremes (middle).

This genetic variation in individual responses to exposure to various toxins raises a difficult ethical, political, and economic question. When regulating levels of a toxin in the environment, should the allowed level be set to protect **(1)** the most sensitive individuals (at great cost) or **(2)** the average person?

The harm caused by a substance can also be affected by:

- *Solubility*. *Water-soluble toxins* (which are often inorganic compounds) can move throughout the environment and get into water supplies. *Oil- or fat-soluble toxins* (which are usually organic compounds) can accumulate in body tissues and cells.
- *Persistence*. Many chemicals, such as plastics, chlorofluorocarbons (CFCs), chlorinated hydrocarbons, and plastics, are widely used because of their persistence or resistance to breakdown. However, this persistence also means that they can have long-lasting effects on the health of wildlife and people.
- **Bioaccumulation**, in which some molecules are absorbed and stored in specific organs or tissues at levels higher than normally would be expected.
- **Biomagnification**, in which the levels of some toxins in the environment are magnified as they pass through food chains and webs (Figure 16-4). Examples of chemicals that can be biomagnified include long-lived, fat-soluble organic compounds such as **(1)** the pesticide DDT, **(2)** PCBs (oily chemicals used in electrical transformers), and **(3)** some radioactive isotopes (such as strontium-90, Table 3-2, p. 62). Stored in body fat, such chemicals can be passed along to offspring during gestation or egg laying and as mothers nurse their young.
- *Chemical interactions* that can decrease or multiply the harmful effects of a toxin. An *antagonistic interaction* can reduce the harmful response. For example, vitamins E and A apparently interact to reduce the body's response to some carcinogens. A *synergistic interaction* (p. 52) multiplies harmful effects. For example, workers exposed to asbestos increase their chances of getting lung cancer 20-fold. However, asbestos workers who also smoke have a 400-fold increase in lung-cancer rates.

The type and amount of health damage that result from exposure to a chemical or other agent are called the **response**. An *acute effect* is an immediate or rapid harmful reaction to an exposure; it can range from dizziness or a rash to death. A *chronic effect* is a permanent or long-lasting consequence (kidney or liver damage, for example) of exposure to a harmful substance.

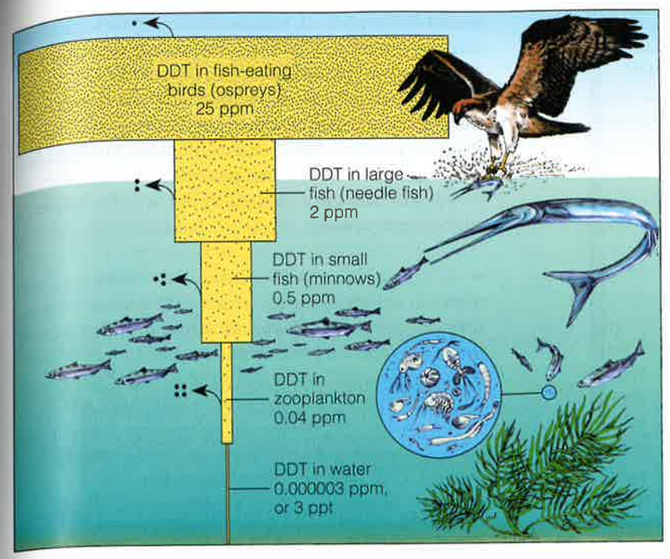

Figure 16-4 *Bioaccumulation* and *biomagnification*. DDT is a fat-soluble chemical that can bioaccumulate in the fatty tissues of animals. In a food chain or food web, the accumulated concentrations of DDT can be biologically magnified in the bodies of animals at each higher trophic level. This diagram shows that the concentration of DDT in the fatty tissues of organisms was biomagnified about 10 million times in this food chain in an estuary near Long Island Sound. If each phytoplankton organism in such a food chain takes up from the water and retains one unit of DDT, a small fish eating thousands of zooplankton (which feed on the phytoplankton) will store thousands of units of DDT in its fatty tissue. Then each large fish that eats 10 of the smaller fish will ingest and store tens of thousands of units, and each bird (or human) that eats several large fish will ingest hundreds of thousands of units. Dots represent DDT, and arrows show small losses of DDT through respiration and excretion.

Should We Be Concerned About Trace Levels of Toxic Chemicals in the Environment and in Our Bodies? The answer is that it depends on the chemical and its concentration. The detection of trace amounts of a chemical in air, water, or food does not necessarily mean that it is there at a level harmful to most people or to wildlife.

A basic concept of toxicology is that any synthetic or natural chemical (even water) can be harmful if ingested in a large enough quantity. Drinking 100 cups of strong coffee one after another would expose most people to a lethal dosage of caffeine. Similarly, downing 100 tablets of aspirin or 1 liter (1.1 quarts) of pure alcohol (ethanol) would kill most people.

The critical question is how much exposure to a particular toxic chemical causes a harmful response. This is the meaning of the quote by German scientist Paracelsus about the dose making the poison (found at the beginning of this chapter).

Most chemicals have some safe or threshold level of exposure below which their harmful effects are insignificant because:

- The human body has mechanisms for breaking down (usually by enzymes found in the liver), diluting, or excreting small amounts of most toxins to keep them from reaching harmful levels.
- Individual cells have enzymes that can repair damage to DNA and protein molecules.
- Cells in some parts of the body (such as the skin and linings of the gastrointestinal tract, lungs, and blood vessels) reproduce fast enough to replace damaged cells. However, such high rates of cell reproduction can sometimes be altered by exposure to ionizing radiation and certain chemicals so that cell growth accelerates and creates a nonmalignant or malignant (cancerous) tumor.

Some people have the mistaken idea that all natural chemicals are safe and all synthetic chemicals are harmful. In fact, many synthetic chemicals are quite safe if used as intended, and many natural chemicals are deadly. For example, the average person is far more likely to be killed by aflatoxin in peanut butter than by lightning or a shark. However, the chance of dying from eating several spoonfuls of peanut butter a day is quite small.

In addition, the ability of chemists to detect increasingly small amounts of potentially toxic chemicals in air, water, and food can give the false impression that dangers from toxic chemicals are increasing. In 1980, chemists could routinely detect concentrations of substance in parts per million (ppm) Table 3-1, p. 61. By 1990, chemists could detect parts per billion (ppb) and today they can detect concentrations of parts per trillion (ppt) and in some cases parts per quadrillion (ppq).

What Is a Poison? Legally, a **poison** is a chemical that has an LD_{50} of 50 milligrams or less per kilogram of body weight. The **LD_{50}** is the **median lethal dose**: the amount of a chemical received in one dose that kills exactly 50% of the animals (usually rats and mice) in a test population (usually 60–200 laboratory animals) within a 14-day period (Figure 16-5).

Chemicals vary widely in their toxicity (Table 16-1). Some poisons can cause serious harm or death after a single acute exposure at extremely low dosages.

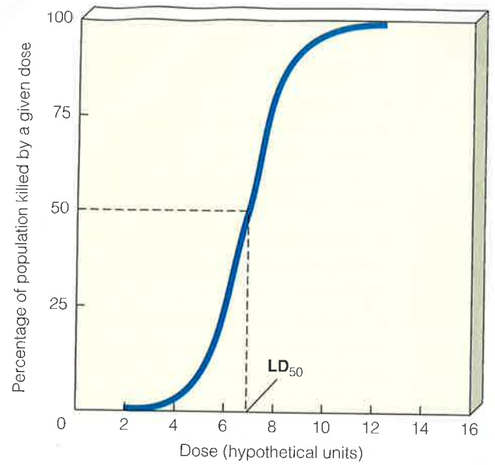

Figure 16-5 Hypothetical dose–response curve showing determination of the LD_{50}, the dosage of a specific chemical that kills 50% of the animals in a test group.

Others cause such harm only at such huge dosages that it is nearly impossible to get enough into the body. Most chemicals fall between these two extremes.

What Methods Do Scientists Use to Determine Toxicity? Scientists use three methods to determine the level at which a substance poses a health threat:

- *Case reports* (usually made by physicians) provide information about people suffering some adverse health effect or death after exposure to a chemical. Such information often involves accidental poisonings, drug overdoses, homicides, or suicide attempts. Most case reports are not a reliable source for determining toxicity because the actual dosage and the exposed person's health status often are not known. However, such reports can provide clues about environmental hazards and suggest the need for laboratory investigations.

- *Laboratory investigations* (usually on test animals) are used to determine **(1)** toxicity, **(2)** residence time, **(3)** what parts of the body are affected, and **(4)** sometimes how the harm takes place.

- **Epidemiology** ("ep-i-deem-ee-OL-oh-gee") in populations of humans exposed to certain chemicals or diseases is used to find out why some people get sick and others do not.

How Are Laboratory Experiments Used to Determine Toxicity? Acute toxicity and chronic toxicity usually are determined by exposing a population of live laboratory animals (especially mice and rats, which are small and prolific and can be housed inexpensively in large numbers) to measured doses of a specific substance under controlled conditions. Animal tests take 2–5 years and cost $200,000 to $2 million per substance tested.

Animal welfare groups want to limit or ban all use of test animals (or to ensure that experimental animals are treated in the most humane manner possible). More humane methods for carrying out toxicity tests include using **(1)** bacteria, **(2)** cell and tissue cultures, and **(3)** chicken egg membranes. In 1999, scientists developed a cheaper and much more sensitive way to determine toxicity by measuring changes in the electrical properties of individual animal cells every quarter-second 24 hours a day.

These alternatives can greatly decrease the use of animals for testing toxicity. However, scientists point out that some animal testing is needed because the alternative methods cannot adequately mimic the complex biochemical interactions of a live animal.

Acute toxicity tests are run to develop a **dose–response curve**, which shows the effects of various dosages of a toxic agent on a group of test organisms (Figure 16-6). Such tests are *controlled experiments* in which the effects of the chemical on a *test group* are compared with the responses of a *control group* of organisms not exposed to the chemical. Care is taken to ensure that organisms in each group are as identical as possible in age, health status, and genetic makeup and that they are exposed to the same environmental conditions.

Fairly high dosages are used to reduce the number of test animals needed, obtain results quickly, and lower costs. Otherwise, tests would have to be run on millions of laboratory animals for many years, and manufacturers could not afford to test most chemicals. For the same reasons, the results of high-dose exposures usually are extrapolated to low-dose levels using mathematical models. Then the extrapolated low-dose results on the test organisms are extrapolated to humans to estimate LD_{50} values for acute toxicity (Table 16-1).

According to the *nonthreshold dose–response model* (Figure 16-6, left), any dosage of a toxic chemical or ionizing radiation causes harm that increases with the dosage. Many chemicals that cause birth defects or cancers show this kind of response.

With the *threshold dose–response model* (Figure 16-6, right) there is a threshold dosage before any detectable harmful effects occur, presumably because the body can repair the damage caused by low dosages of some substances. It is extremely difficult to establish which of these models applies at low dosages. To be on the safe side, the nonthreshold dose–response model often is assumed.

Some scientists challenge the validity of extrapolating data from test animals to humans because human physiology and metabolism often are different from those of the test animals. Also, different species of test animals can react differently to the same toxin because of differences in body size, physiology, metabolism, and toxin sensitivity (Figure 16-3). Other scientists counter that such tests and models work fairly well (especially for revealing cancer risks) when the correct experimental animal is chosen or when a chemical is toxic to several different test animal species.

Table 16-1 Toxicity Ratings and Average Lethal Doses for Humans

Toxicity Rating	LD_{50} (milligrams per kilogram of body weight)*	Average Lethal Dose†	Examples
Supertoxic	Less than 0.01	Less than 1 drop	Nerve gases, botulism toxin, mushroom toxins, dioxin (TCDD)
Extremely Toxic	Less than 5	Less than 7 drops	Potassium cyanide, heroin, atropine, parathion, nicotine
Very Toxic	5–50	7 drops to 1 teaspoon	Mercury salts, morphine, codeine
Toxic	50–500	1 teaspoon to 1 ounce	Lead salts, DDT, sodium hydroxide, sodium fluoride, sulfuric acid, caffeine, carbon tetrachloride
Moderately Toxic	500–5,000	1 ounce to 1 pint	Methyl (wood) alcohol, ether, phenobarbital, amphetamines (speed), kerosene, aspirin
Slightly toxic	5,000–15,000	1 pint to 1 quart	Ethyl alcohol, Lysol, soaps
Essentially nontoxic	15,000 or greater	More than 1 quart	Water, glycerin, table sugar

*Dosage that kills 50% of individuals exposed
†Amounts of substances that are liquids at room temperature when given to a 70.4-kilogram (155-Pound) human

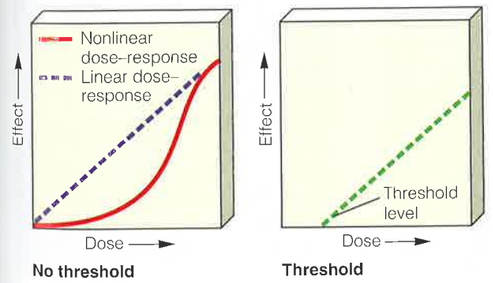

Figure 16-6 Hypothetical dose–response curves. The linear and nonlinear curves in the left graph show that exposure to any dosage of a chemical or ionizing radiation has a harmful effect that increases with the dosage. The curve on the right shows that a harmful effect occurs only when the dosage exceeds a certain *threshold level*. There is much uncertainty about which of these models applies to various harmful agents because of the difficulty in estimating the response to very low dosages. (Adapted from *Environmental Science*, 5/E by Chiras, p. 352, fig. 19.12. Copyright ©1998 by Wadsworth)

How Is Epidemiology Used to Determine Toxicity? In an *epidemiological study*, the health of people exposed to a particular toxic agent or disease organism (the experimental group) is compared with the health of another group of statistically similar people not exposed to these conditions (the control group). The goal of such studies to establish a strong, moderate, weak, or no statistical association between a hazard and a health problem.

Three major limitations of epidemiology are that **(1)** too few people have been exposed to sufficiently high levels of many toxic agents to allow detection of statistically significant differences, **(2)** conclusively linking an observed effect with exposure to a particular hazard is very difficult because people are exposed to many different toxic agents and disease-causing factors throughout their lives, and **(3)** it cannot be used to evaluate hazards from new technologies, substances, or diseases to which people have not been exposed.

How Valid Are Estimates of Toxicity? As we have seen, all methods for estimating toxicity levels and risks have serious limitations. However, they are all we have. To take this uncertainty into account and minimize harm, standards for allowed exposure to toxic substances and ionizing radiation typically are set at levels 1/100 or even 1/1,000 of the estimated harmful levels.

Despite their many limitations, carefully conducted and evaluated toxicity studies are important sources of information we can use to understand dose–response effects and to estimate and set exposure standards. However, citizens, lawmakers, and regulatory officials must recognize the huge uncertainties and guesswork involved in all such studies.

16-3 CHEMICAL HAZARDS

What Are Toxic and Hazardous Chemicals? **Toxic chemicals** generally are defined as substances that are fatal to more than 50% of test animals (LD_{50}) at given concentrations. **Hazardous chemicals** cause harm by **(1)** being flammable or explosive, **(2)** irritating or damaging the skin or lungs (strong acidic or alkaline substances such as oven cleaners), **(3)** interfering with or preventing oxygen uptake and distribution (asphyxiants such as carbon monoxide and hydrogen sulfide), or **(4)** inducing allergic reactions of the immune system (allergens).

What Are Mutagens? **Mutagens** are agents, such as chemicals and ionizing radiation, that cause random *mutations*, or changes in the DNA molecules found in cells. Mutations in a sperm or egg cell can be passed on to future generations and cause diseases such as manic depression, cystic fibrosis, hemophilia, sickle-cell anemia, Down's syndrome, and some types of cancer. Mutations in other cells are not inherited but may cause harmful effects.

Most mutations are harmless, probably because all organisms have biochemical repair mechanisms that can correct mistakes or changes in the DNA code. In addition, some mutations play a vital role in evolution (p. 107). There is no agreement on the best ways to test substances for genetic damage in humans.

What Are Teratogens? **Teratogens** are chemicals, radiation, or viruses that cause birth defects while the human embryo is growing and developing during pregnancy, especially during the first 3 months. Chemicals known to cause birth defects in laboratory animals include PCBs, thalidomide, steroid hormones, and heavy metals such as arsenic, cadmium, lead (p. 540), and mercury.

What Are Carcinogens? According to the WHO, environmental and lifestyle factors play a key role in causing or promoting up to 80% of all cancers. Major sources of carcinogens are cigarette smoke (30–40% of cancers), diet (20–40%), occupational exposure (5–15%), and environmental pollutants (1–10%). Inherited genetic factors and certain viruses cause about 10–20% of all cancers.

Carcinogens are chemicals, radiation, or viruses that cause or promote the growth of a malignant (cancerous) tumor, in which certain cells multiply uncontrollably. Many cancerous tumors spread by **metastasis** when malignant cells break off from tumors and travel in body fluids to other parts of the body. There, they start new tumors, making treatment much more difficult.

Because there are more than 100 types of cancer (depending on the types of cells involved), there are many different causes. These include genetic predisposition, viral infections, and exposure to various mutagens and carcinogens.

Typically, 10–40 years may elapse between the initial exposure to a carcinogen and the appearance of detectable symptoms. Partly because of this time lag, many healthy teenagers and young adults have trouble believing that their smoking (p. 396), drinking, eating, and other lifestyle habits today could lead to some form of cancer before they reach age 50.

How Can Chemicals Harm the Immune, Nervous, and Endocrine Systems? Since the 1970s there has been a growing body of research on wildlife and laboratory animals and epidemiological studies of humans indicating that long-term (often low-level) exposure to various toxic chemicals in the environment can disrupt the body's immune, nervous, and endocrine systems.

The *immune system* consists of specialized cells and tissues that protect the body against disease and harmful substances by forming antibodies to invading agents and rendering them harmless. Viruses such as the human immunodeficiency virus (HIV), ionizing radiation, malnutrition, and some synthetic chemicals can weaken the human immune system. This can leave the body wide open to attacks by allergens, infectious bacteria, viruses, and protozoans. Recent studies of laboratory animals and wildlife as well as epidemiological studies of humans (especially in developing countries) have linked immune system suppression to several widely used pesticides.

Synthetic chemicals in the environment threaten the human *nervous system* (brain, spinal cord, and peripheral nerves). Many poisons are *neurotoxins*, which attack nerve cells (neurons). Examples are **(1)** chlorinated hydrocarbons (DDT, PCBs, dioxins), **(2)** organophosphate pesticides (Table 20-1, p. 504), **(3)** formaldehyde, **(4)** various compounds of arsenic, mercury, lead, and cadmium, and **(5)** widely used industrial solvents such as trichloroethylene (TCE), toluene, and xylene.

The *endocrine system* is a complex network of glands and hormones that regulates many of the body's functions. Each type of hormone has a specific molecular shape that allows it to attach only to certain cell receptors (Figure 16-7, left). Once bonded together, the hormone and its receptor molecule move to the cell's nucleus to execute the chemical message carried by the hormone.

The endocrine glands release extremely small amounts of *hormones* into the bloodstream that act as natural chemical messengers to control body functions such as sexual reproduction, growth, development, and behavior in humans and other animals. These naturally occurring hormones have profound effects on the human nervous, reproductive, and immune systems. There is concern that human exposure to low levels of synthetic chemicals, known as *hormonally active agents* (HAAs), can mimic and disrupt the effects of natural hormones (Connections, p. 404).

Why Do We Know So Little About the Harmful Effects of Chemicals? According to risk assessment expert Joseph V. Rodricks, "Toxicologists know a great deal about a few chemicals, a little about many, and next to nothing about most." The U.S. National Academy of Sciences estimates that only about 10% of at least 75,000 chemicals in commercial use have been thoroughly screened for toxicity, and only 2% have been adequately tested to determine whether they are carcinogens, teratogens, or mutagens. Hardly any of the chemicals in commercial use have been screened for damage to the nervous, endocrine, and immune systems.

Each year about 1,000 new synthetic chemicals are introduced into the marketplace, with little knowledge about their potentially harmful effects. Currently, federal and state governments do not regulate about 99.5% of the commercially used chemicals in the United States. There are three major reasons for this lack of information and regulation.

- Under existing laws most chemicals are considered innocent until proven guilty. No one is required to investigate whether they are harmful.
- There are not enough funds, personnel, facilities, and test animals to provide such information for more than a small fraction of the many chemicals we encounter in our daily lives.
- It is too difficult and expensive to analyze the combined effects of multiple exposures to various chemicals and the possible interactions of such chemicals. For example, just studying the possible different three-chemical interactions of the 500 most widely used industrial chemicals would take 20.7 million experiments—a physical and financial impossibility.

What Is the Precautionary Approach? The difficulty and expense of getting information about the harmful effects of chemicals are one reason an increasing number of scientists and health officials are pushing for much greater emphasis on *pollution prevention*. This strategy greatly reduces the need for statistically uncertain and controversial toxicity studies and exposure standards. It also reduces the risk posed by potentially hazardous chemicals and products and their possible but poorly understood multiple interactions.

This approach is based on the **precautionary principle**. According to this concept, when there is considerable scientific uncertainty about potentially serious harm from chemicals or technologies, decision makers should act to prevent harm to humans and the environment. It is based on familiar axioms: Look before you leap, better safe than sorry, and an ounce of prevention is worth a pound of cure.

Under this approach, those proposing to introduce a new chemical or technology would bear the burden

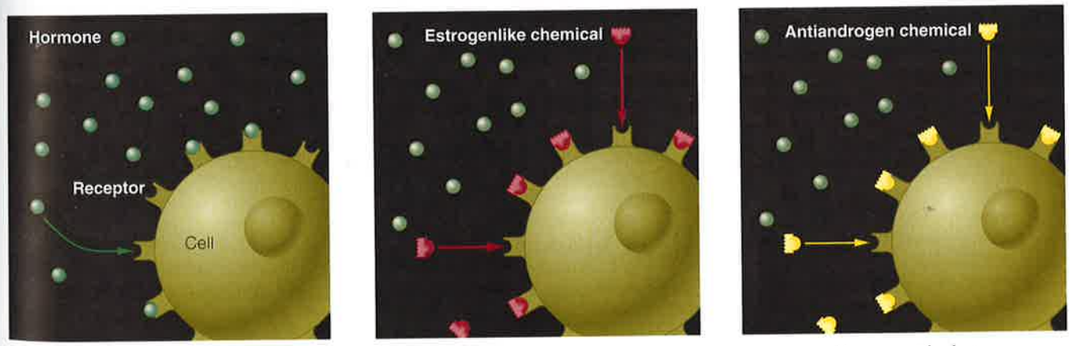

Figure 16-7 Hormones are molecules that act as messengers in the endocrine system to regulate various bodily processes, including reproduction, growth, and development. Each type of hormone has a unique molecular shape that allows it to attach to specially shaped receptors on the surface of or inside cells and transmit its chemical message (left). Molecules of certain pesticides and other molecules have shapes similar to those of natural hormones. Some of these hormone impostors, called *hormone mimics*, disrupt the endocrine system by attaching to estrogen receptor molecules (center). Others, called *hormone blockers*, prevent natural hormones such as androgens (male sex hormones) from attaching to their receptors (right). Some pollutants called *thyroid disrupters* may disrupt hormones released by thyroid glands and cause growth and weight disorders and brain and behavioral disorders.

Are Hormone Disrupters and Mimics a Health Threat?

CONNECTIONS

Over the last 15 years experts from a number of disciplines have been piecing together field studies on wildlife, studies on laboratory animals, and epidemiological studies of human populations. This analysis suggests that a variety of human-made chemicals can act as *hormone* or *endocrine disrupters*, known as *hormonally active agents (HAAs)*. By 1998, 60 endocrine disrupters had been identified, and with further testing and screening the list of HAAs could reach several hundred.

Some, called *hormone mimics*, are estrogenlike chemicals that disrupt the endocrine system by attaching to estrogen receptor molecules (Figure 16-7, center).

Others, called *hormone blockers*, disrupt the endocrine system by preventing natural hormones such as androgens (male sex hormones) from attaching to their receptors (Figure 16-7, right). There is also growing concern about pollutants that can act as *thyroid disrupters* and cause growth, weight, brain, and behavioral disorders.

Most natural hormones are broken down or excreted. However, many synthetic hormone impostors are stable, fat-soluble compounds whose concentrations can be biomagnified as they move through food chains and webs (Figure 16-4). Thus, they can pose a special threat to humans and other carnivores dining at the top of food webs.

Numerous wildlife and laboratory studies reveal various possible effects of estrogen mimics and hormone blockers (HAAs). Here are a few of many examples:

- Ranch minks fed Lake Michigan fish contaminated with endocrine disrupters such as DDT and PCBs failed to reproduce.
- Exposure to PCBs has reduced penis size in some test animals and in 118 boys born to women who were exposed to a PCB spill in Taiwan in 1979.
- A 1999 study by Michigan State University zoologists found that female rats exposed to PCBs were reluctant to mate, raising the possibility that such contaminants could cause low sex drives in women.
- In 1973, estrogen mimics called PBBs accidentally got into cattle feed in Michigan, and from there into beef. Pregnant women who ate the beef (and whose breast milk had high levels of PBBs) had sons with undersized penises and malformed testicles.
- During the past 50 years there have been dramatic increases in testicular and prostate cancer in humans almost everywhere.
- Average sperm counts among men in the United States and Europe have declined by 50% during the past 60 years.

In 1999, the U.S. National Academy of Sciences released a report based on a 4-year review of the scientific literature on hormone disrupters (HAAs). The panel concluded that far too little is known about the effects of such chemicals to come to a definitive conclusion about their effects on humans.

Scientists on this panel called for greatly increased research to **(1)** verify current frontier science findings and **(2)** determine whether low levels of most hormone-disrupting chemicals in the environment pose a threat to the human population. However, the report also concluded that at present the at least 75,000 industrial chemicals in commercial use cannot be tested to determine whether they are hormone disrupters because the necessary tests do not exist.

If such research (which will take decades) shows that exposure to small amounts of hormone disrupters is harmful to humans and some forms of wildlife, the only reasonable choice may be to prevent such chemicals from reaching the environment. This will be a difficult and controversial economic and political decision.

Some health scientists believe that we should begin sharply reducing the use of potential hormone disrupters now because they meet the two requirements of the *precautionary principle*: great scientific uncertainty and a reasonable suspicion of harm.

Critical Thinking

1. Do you consider the possible threat from hormone disrupters a problem that could affect you or any child you might have? Explain.
2. Do you believe that the precautionary approach should be used to deal with this problem while more definite research is carried out over the next two decades? Explain. What harmful effects could using this approach have on the economy and on your lifestyle? Do such effects outweigh the risks? Explain.

of establishing its safety. In other words, new chemicals and technologies would be assumed to be guilty until proven innocent. Manufacturers and businesses contend that doing this would make it too expensive and almost impossible to introduce any new chemical or technology.

16-4 BIOLOGICAL HAZARDS: DISEASE IN DEVELOPED AND DEVELOPING COUNTRIES

What Are Nontransmissible Diseases? A **nontransmissible disease** is not caused by living organisms and does not spread from one person to another. Examples are cardiovascular (heart and blood vessel) disorders, most cancers, diabetes, bronchitis, emphysema, and malnutrition. Such diseases typically have multiple (and often unknown) causes and tend to develop slowly and progressively over time.

What Are Transmissible Diseases? A **transmissible disease** is caused by a living organism (such as a bacterium, virus, protozoa, or parasite) and can be spread from one person to another. These infectious agents are called *pathogens* and are spread by air, water, food, body fluids, some insects, and other nonhuman carriers called *vectors*.

Typically, a *bacterium* is a one-celled microorganism capable of replicating itself by simple cell division. A *virus* is a microscopic, noncellular infectious agent. Its DNA contains instructions for making more viruses, but it has no apparatus to do so. To replicate, a virus must invade a host cell and take over the cell's DNA to create a factory for producing more viruses.

According to the WHO and UNICEF, every year in developing countries at least 2 million children under age 5 die of mostly preventable infectious diseases—an average of at least 5,500 premature deaths per day. About 80% of all illnesses in developing countries are caused by waterborne infectious diseases (such as diarrhea, hepatitis, typhoid fever, and cholera), mainly from unsafe drinking water and inadequate sanitation systems.

Antibiotics have greatly reduced the incidence of infectious disease caused by bacteria. However, their widespread use and misuse have increased the genetic resistance of many disease-causing bacteria, which can reproduce rapidly (Spotlight, p. 406).

Worldwide, infectious diseases cause about one of every four deaths each year. According to the WHO, the world's seven deadliest infectious diseases are **(1)** *acute respiratory infections*, mostly pneumonia and flu (caused by bacteria and viruses and killing about 3.7 million people per year), **(2)** *HIV/AIDS* (a viral disease, 2.6 million), **(3)** *diarrheal diseases* (caused by bacteria and viruses, 2.5 million), **(4)** *tuberculosis* (TB, a bacterial disease, 2 million; Case Study, p. 407), **(5)** *malaria* (caused by parasitic protozoa, 1.5 million), **(6)** *measles* (a viral disease, 1 million), and **(7)** *hepatitis B* (a viral disease, 1 million).

How Rapidly Are Viral Diseases Spreading? Viral diseases include **(1)** *influenza* or *flu* (transmitted by the bodily fluids or airborne emissions of an infected person), **(2)** *Ebola* (transmitted by the blood or other body fluids of an infected person), **(3)** *rabies* (transmitted by dogs, coyotes, raccoons, skunks, and bats), and **(4)** *HIV/AIDS*. Viruses, like bacteria, can genetically adapt rapidly to different conditions.

Although health officials worry about the emergence of new viral diseases (such those caused by Ebola viruses), they recognize that the greatest virus health threat to humans is the emergence of new, very virulent stains of influenza. Flu viruses move through the air and are highly contagious. During 1918 and 1919, a flu epidemic infected more than half the world's population and killed 20–30 million people (including about 500,000 in the United States). Today, flu kills about 1 million people per year (20,000 of them in the United States).

Sex can be dangerous to one's health. Every day an estimated 114 million acts of sexual intercourse take place in the world. Some 919,000 of these acts lead to conception and about 360,000 pass on a bacterium or virus that causes a sexually transmitted disease (STD). In the United States, STDs infect about 15.3 million people each year.

According to a 1998 report by the American Social Health Association, at least one in every three sexually active people in the United States will contract an STD by the age of 24. Some of these diseases can cause infertility in men and women. Others can cause warts and genital cancers or, in the case of HIV, death.

There is a growing threat from the spread of *acquired immune deficiency syndrome* or *AIDS*, which is caused by HIV. The virus itself is not deadly, but it kills immune cells and leaves the body defenseless against infectious bacteria and other viruses. HIV can be transmitted **(1)** during unprotected sexual activity, **(2)** from one intravenous drug user to another through shared needles, **(3)** from an infected mother to an infant during birth, and **(4)** by exposure to infected blood.

According to the WHO, in December 2000 some 36.1 million people (22 million of them in sub-Saharan Africa and 1.2 million of them children under age 15) were infected with HIV. During 2000, 5.4 million people (80% of them in Africa and Asia) were newly infected with HIV—an average of 15,300 new infections per day.

Within about 7–10 years, 95% of those with HIV develop AIDS. This long incubation period means that infected people often spread the virus for several years without knowing that they are infected. So far, there is no cure for AIDS, although drugs may help some infected people live longer (if they can afford the treatment).

By January 2000, about 19 million people (3.6 million of them children under age 15 and 420,000 people in the United States) had died of AIDS-related diseases. About 2.6 million of these deaths occurred in 1999 (1.8 million of them in Africa). In the 29 African countries hit hardest by AIDS, the average life expectancy at birth is 7 years less than it would have been without the presence of AIDS. According to the WHO, between 2000 and 2010 AIDS probably will kill as many people as all the wars in the 20th century combined.

Are We Losing the War Against Infectious Bacteria?

SPOTLIGHT

There is growing and alarming evidence that we may be losing our war against infectious bacterial diseases because bacteria are among the earth's ultimate survivors. When a colony of bacteria is dosed with an antibiotic such as penicillin, most of the bacteria are killed.

However, a few have mutant genes that make them immune to the drug. Through natural selection (Figure 5-6, left, p. 110), a single mutant can pass such traits on to most of its offspring, which can amount to 16,777,216 in only 24 hours.

Each time this strain of bacterium is exposed to penicillin or some other antibiotic, a larger proportion of its offspring are genetically resistant to the drug. The rapid multiplication of resistant bacteria in a victim is made easier because the antibiotics also wipe out their bacterial competitors.

Even worse, bacteria can become genetically resistant to antibiotics they have never been exposed to. When a resistant and a nonresistant bacterium touch one another (say, on a hospital bedsheet or in a human stomach), they can exchange a small loop of DNA called a plasmid, thereby transferring genetic resistance from one organism to another.

The incredible genetic adaptability of bacteria is one reason the world faces a potentially serious rise in the incidence of some infectious bacterial diseases once controlled by antibiotics. Other factors also play a key role, including **(1)** spread of bacteria (some beneficial and some harmful) around the globe by human travel and the trade of goods, **(2)** overuse of antibiotics by doctors, often at the insistence of their patients, **(3)** failure of many patients to take all of their prescribed antibiotics, which promotes bacterial resistance, **(4)** availability of antibiotics in many countries without prescriptions, **(5)** overuse of pesticides (p. 508), which increases populations of pesticide-resistant insects and other carriers of bacterial diseases, and **(6)** widespread use of antibiotics in the livestock and dairy industries to control disease in livestock animals (about 20% of their use) and to promote animal growth (about 80% of their use).

The result of these factors acting together is that every major disease-causing bacterium now has strains that resist at least one of the roughly 160 antibiotics we use to treat bacterial infections. In 1998, health officials were alarmed to learn of the existence of a strain of bubonic plague in Madagascar that is resistant to multiple antibiotics.

In 2000, officials at the U.S. Centers for Disease Control and Prevention estimated that about 2.2 million people (most with a weakened immunity system) a year get sick and at least 88,000 die from infectious diseases they pick up in U.S. hospitals, nursing homes, or home health-care settings. Most of these infections are caused by **(1)** contaminated catheters, intravenous lines, and breathing tubes and **(2)** failure of doctors and other health-care personnel to carefully wash their hands with water or with waterless alcohol-based antimicrobial hand rubs and frequently change their latex gloves. Patients can reduce such infections by asking any doctor or health-care worker coming into their room, "Did you wash your hands?" or "Did you change your gloves?"

There is growing controversy over the widespread use of antibiotics to increase the growth rate of about 80% of the livestock animals raised each year in the United States, mainly cattle, pigs, and poultry. Each year this use accounts for about 40% of all antibiotics used in the United States and for more than half the global production of antibiotics.

The European Union, the World Health Organization, the American Public Health Association, and the U.S. Centers for Disease Control and Prevention all favor the immediate phaseout of all antibiotics used to promote growth in livestock animals that are the same as or closely related to antibiotics used in humans. Several European countries have imposed such bans, and since 1986 Sweden has banned all use of antibiotics for growth promotion in livestock.

A 1999 study by the U.S. National Academy of Sciences concluded that **(1)** bacteria that resist antibiotics can be passed from food animals to people, **(2)** not enough is known to determine the risks this poses to human health, and **(3)** phasing out antibiotics used as growth promoters would cost about $5–10 per person annually in higher meat and fish prices.

Critical Thinking

1. What role, if any, have you played in the increase in genetic resistance of bacteria to widely used antibiotics? List three ways to reduce this threat.

2. Do you believe that the use of the same antibiotics to treat human illness and to fatten livestock should be banned in the United States (or the country where you live)? Explain. Would you favor using small amounts of such antibiotics to treat disease in livestock?

Once a viral infection starts, it is much harder to fight than infections by bacteria and protozoans. Only a few antiviral drugs exist because most drugs that will kill a virus also harm the cells of its host. Treating viral infections (such as colds, flu, and most mild coughs and sore throats) with antibiotics is useless and increases genetic resistance in disease-causing bacteria (Spotlight, above).

Medicine's only effective weapons against viruses are vaccines that stimulate the body's immune system to produce antibodies to ward off viral infections. Immunization with vaccines has helped tame viral diseases such as smallpox, polio, rabies, influenza, measles, and hepatitis B (Solutions, p. 408).

Connections: What Factors Can Affect the Spread of Transmissible Diseases? Outbreaks of infectious diseases often occur because of a change in the physical, social, or biological environment of disease reservoirs, carrier vectors, or exposure to new host populations. Important factors include the following:

- *Increased international air travel*, which can rapidly spread diseases such as flu, measles, cholera, yellow fever, and TB. Between 1960 and 2000, international air travel increased from about 50 million to 500 million people per year.

The Global Tuberculosis Epidemic

CASE STUDY

Since 1990 one of the world's most underreported stories has been the rapid spread of tuberculosis (TB). According to the World Health Organization, this highly infectious bacterial disease kills about 2 million people and infects about 8 million people per year (Figure 16-8). It is the leading cause of death among women of reproductive age. In India, where nearly half the population is infected with TB, the disease kills a half a million people each year.

The bacterium causing TB infection moves from person to person, mainly in airborne droplets produced by coughing, sneezing, singing, or even talking. Whereas TB kills about 2 million people per year, highly publicized Ebola viruses, which are hard to transmit, have killed about 1,000 people over the past 20 years—an average of 50 people per year.

About one of every three people in the world is infected with the TB bacillus. During their lifetime about 5–10% of these people will become sick or infectious with active TB, especially when their immune system is weakened. Left untreated, each person with active TB will infect 10–15 other people. Because many of the infected people do not appear to be sick and about half of them do not even know they are infected, this serious health problem has been called a *silent global epidemic*.

Until this resurgence, the incidence of TB had fallen sharply (except among the poor). This occurred mostly because of **(1)** prevention programs (such as X-ray screening and detection of people with active TB) and **(2)** treatment with antibiotics, which began in the 1940s. Before antibiotics, the spread of the disease was controlled by isolating patients with active TB in sanitariums until they died or recovered.

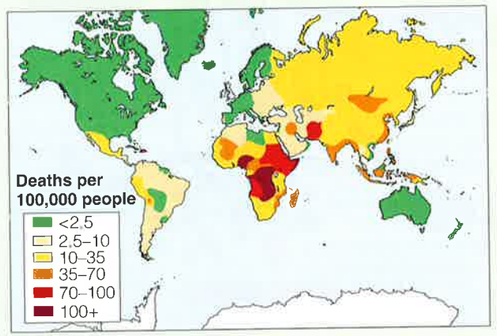

Figure 16-8 The current global tuberculosis epidemic. This easily transmitted disease is spreading rapidly and now kills about 2 million people a year. (Data from World Health Organization)

Major reasons for the recent increase in TB are **(1)** poor TB screening and control programs (especially in developing countries, where about 95% of the new cases occur), **(2)** development of strains of the tuberculosis bacterium that are genetically resistant to almost all effective antibiotics (typically leading to mortality rates of more than 50%), **(3)** population growth and increased urbanization (which increase contacts among people), **(4)** poverty, and **(5)** the spread of AIDS, which greatly weakens the immune system and allows TB bacteria to multiply.

Slowing the spread of the disease involves early identification and treatment of people with active TB, usually those with a chronic cough. Treatment with a combination of four inexpensive drugs can cure 90% of those with active TB. However, to be successful the drugs must be taken every day for 6 to 8 months. Because the symptoms disappear after a few weeks, many patients think they are cured and stop taking the drugs. This allows the disease to recur in a hard-to-treat form. It then spreads to other people, and drug-resistant strains of TB bacteria develop.

According to the World Health Organization, a worldwide campaign to help control TB would cost about $360 million to help save at least 20 million lives during the next decade.

Critical Thinking

Before you read this report, were you aware of the serious global TB epidemic? Why do you think that this important story has gotten so little media attention compared to other diseases that cause many fewer deaths per year?

Producing an Edible Hepatitis B Vaccine

SOLUTIONS

Worldwide, about 300 million people (most in developing countries) are infected with liver-damaging hepatitis B. Each year about 1 million people die from this disease and there are about 1 million new infections.

A vaccine for hepatitis B has been developed from bioengineered yeast. However, it **(1)** costs about $100 per person, **(2)** requires three shots over a 6-month period, and **(3)** must be refrigerated continuously before use. This makes it impractical to carry out mass immunizations for hepatitis B in developing countries.

Researchers are developing a much cheaper and easily administered vaccine by inserting DNA extracted from the hepatitis B virus into the cells of leaves of plants such as potatoes (Figure 16-9). Mice eating raw potatoes from the plant developed immunity to hepatitis B. Researchers hope to introduce the vaccine into bananas, which might cost as little as 5¢ per dose to produce.

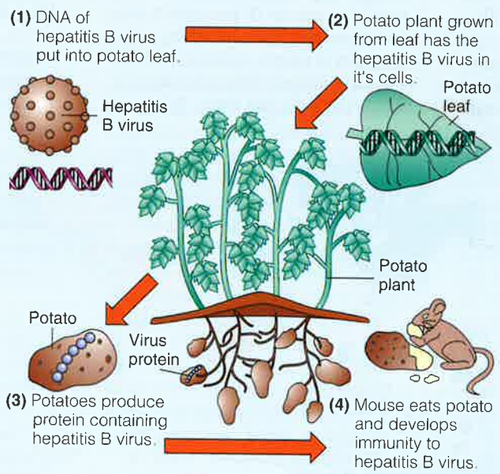

Figure 16-9 Using genetic engineering to produce food crops that contain a vaccine for hepatitis B.

Critical Thinking

What might be some disadvantages of introducing hepatitis B vaccine into the genes of food plants? Do you believe that the advantages of using this vaccine in food outweigh its disadvantages? Explain.

- *Migration to urban areas*, which increases the probability of infection from diseases such as TB (Case Study, p. 407), cholera, and sexually transmitted diseases.
- *Migration to uninhabited rural areas and deforestation in tropical developing countries*, which can expose people to new diseases and disease vectors such as malaria, sleeping sickness, and yellow fever.
- *Migration to suburbs in developed countries*. For example, as more people have moved to wooded suburbs in the eastern United States, they have come into greater contact with ticks infested with bacteria that cause Lyme disease, which causes fever, lethargy, and (sometimes) long-lasting arthritis.
- *Hunger and malnutrition* (p. 267), which increase the number of children killed by infectious diseases such as measles and diarrhea.
- *Increased rice cultivation* in flooded fields and paddies, which creates ideal breeding grounds for mosquitoes and other insects that transmit diseases to humans.
- *Global warming*, which is leading to the spread of tropical infectious diseases such as malaria (Figure 16-10), yellow fever, and dengue fever (called "breakbone fever" by those whose experience the excruciating pain it causes in joints) to temperate areas. A 2000 study by researchers at the Johns Hopkins School of Public Health found that each 1°C (1.8°F) rise in temperature causes an 8% increase in diarrhea in children under age 5 in developing countries.
- *High winds or hurricanes*, which can transfer infectious organisms and carriers of disease (such as insects) from tropical to temperate areas.
- *Accidental introduction of insect vectors*. The Asian tiger mosquito is a vector for dengue fever, yellow fever, and other viruses. In 1985, it was brought accidentally to the United States inside used tires shipped from Asia. Today, this mosquito species has become established in Hawaii and the southeastern United States and has begun extending its range north toward Chicago and Washington, D.C.
- *Flooding*, which **(1)** often contaminates water supplies with raw sewage and **(2)** creates areas of standing water and moist soil that are ideal breeding grounds for mosquitoes and other insects that spread infectious diseases.

Case Study: Malaria, a Protozoal Disease About 45% of the world's population live in tropical and subtropical regions in which malaria is present (Figure 16-10). Currently, an estimated 300–500 million people are infected with malaria parasites worldwide, and there are 270–480 million new cases each year.

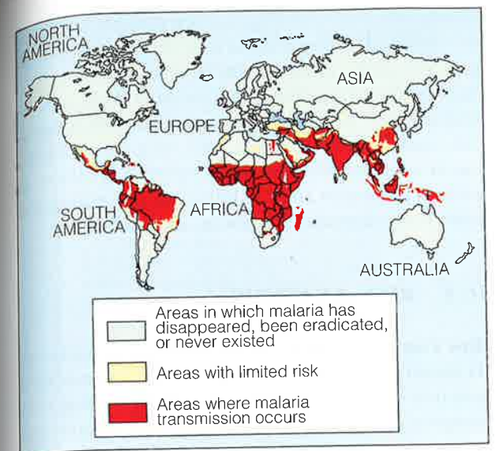

Figure 16-10 Worldwide distribution of malaria. About 45% of the world's current population live in areas in which malaria is present, with the disease killing at least 1.5 million people a year. If the world becomes warmer, as projected by current climate models, by 2046 malaria could affect 60% of the world's population. (Data from the World Health Organization)

Malaria's symptoms come and go and include fever and chills, anemia, an enlarged spleen, severe abdominal pain and headaches, extreme weakness, and greater susceptibility to other diseases. The disease kills about 1.5 million people each year, more than half of them children under age 5.

Malaria is caused by four species of protozoa of the genus *Plasmodium*. Most cases of the disease are transmitted when an uninfected female of any one of 60 species of *Anopheles* mosquito **(1)** bites an infected person, **(2)** ingests blood that contains the parasite, and **(3)** later bites an uninfected person (Figure 16-11). When this happens, *Plasmodium* parasites move out of the mosquito and into the human's bloodstream, multiply in the liver, and then enter blood cells to continue multiplying. Malaria also can be transmitted by blood transfusions or by sharing needles.

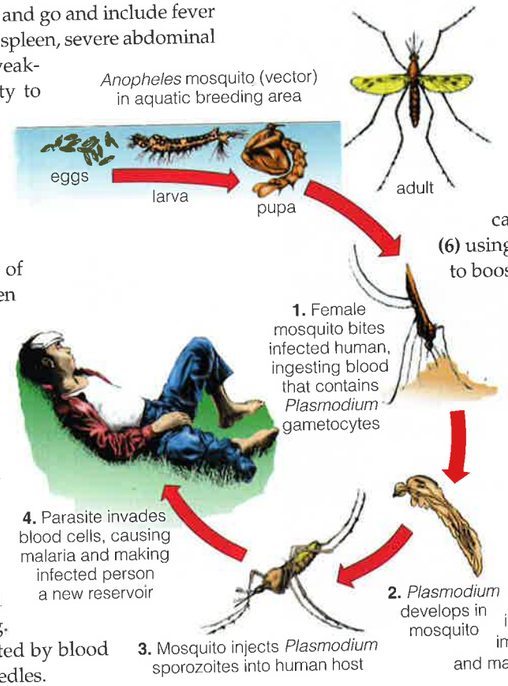

Figure 16-11 The life cycle of malaria. This life cycle of *Plasmodium* circulates from mosquito to human and back to mosquito. Although various species of mosquitoes carry diseases (such as malaria, yellow fever, encephalitis, and dengue fever to humans and heartworm to dogs), mosquitoes play important ecological roles. Their eggs are a major food source for fish, various insects, and frogs and other amphibians, and adult mosquitoes are an important source of food for bats, spiders, and many species of insects and birds.

The malaria cycle repeats itself until immunity develops, treatment is given, or the victim dies. Over the course of human history, malarial protozoa probably have killed more people than all the wars ever fought.

During the 1950s and 1960s, the spread of malaria was sharply curtailed by **(1)** draining swamplands and marshes, **(2)** spraying breeding areas with insecticides, and **(3)** using drugs to kill the parasites in the bloodstream. Since 1970, however, malaria has come roaring back. Most species of the malaria-carrying *Anopheles* mosquito have become genetically resistant to most insecticides. Worse, the *Plasmodium* parasites have become genetically resistant to common antimalarial drugs.

Researchers are working to develop new antimalarial drugs, vaccines, and biological controls for *Anopheles* mosquitoes. However, such approaches are underfunded and have proved more difficult than originally thought. Researchers also are studying the feasibility of altering the genetic makeup of mosquitoes so that they cannot carry and transmit the parasite to humans.

According to health experts, prevention is the best approach to slowing the spread of malaria. Methods include **(1)** increasing water flow in irrigation systems to prevent mosquito larvae from developing (an expensive and wasteful use of water), **(2)** using mosquito nets dipped in a nontoxic insecticide (permethrin) in windows and doors of homes, **(3)** cultivating fish that feed on mosquito larvae (biological control), **(4)** clearing vegetation around houses, **(5)** planting trees that soak up water in low-lying marsh areas where mosquitoes thrive (a method that can degrade or destroy ecologically important wetlands), and **(6)** using zinc and vitamin A supplements to boost children's resistance to malaria.

What Are the Major Diseases in Developed Countries? As a country industrializes, it usually makes an *epidemiological transition*. The infectious diseases of childhood become less important, and the chronic diseases of adulthood (heart disease and stroke, cancer, and respiratory conditions) become more important in causing mortality. In 1999, for example, infectious and parasitic diseases were responsible for 43% of all deaths in developing countries but only 1% in developed countries.

In 1999, about 31% of the deaths in the United States were from heart attacks, 23% from cancer, 7% from strokes, 7% from infectious diseases (mostly pneumonia, influenza, and AIDS), 4% from accidents (half from automobile accidents), 3% from diabetes, and 1% each from suicides, kidney diseases, and liver diseases. Almost two-thirds of these deaths resulted from chronic diseases (such as heart disease, strokes, and cancer) that take a long time to develop and have multiple causes. In 1980, infectious diseases ranked as America's fifth leading killer. By 1999, they were tied with stroke as the third leading cause of death, representing a partial reversal of the epidemiologic transition in the United States.

According to the U.S. Department of Health and Human Services, about 95% of the money spent on health care in the United States each year is used to *treat* rather than to *prevent* disease—one reason why health-care costs are so high and continue to climb. Health experts estimate that changing harmful lifestyle factors could prevent **(1)** 40–70% of all premature deaths, **(2)** one-third of all cases of acute disability, and **(3)** two-thirds of all cases of chronic disability in the United States.

How Can We Reduce Infectious Diseases in Developing Countries? Figure 16-12 lists ways that health scientists and public health officials suggest for preventing or reducing the incidence of infectious diseases that affect humanity. They also call for increased emphasis on preventive health care in developing countries (Solutions, p. 413).

The WHO estimates that only 2% of the world's global research and development funds are devoted to infectious diseases in developing countries, even though more people worldwide suffer and die from these diseases than from all others combined. Indeed, according to 2000 study by the International Federation of Red Cross, an estimated 150 million people have died from tuberculosis, malaria, and AIDS since 1945, compared to 23 million in wars. In 1995, the world spent $864 billion on military protection and $15 billion on preventing and controlling tuberculosis, malaria, and AIDS.

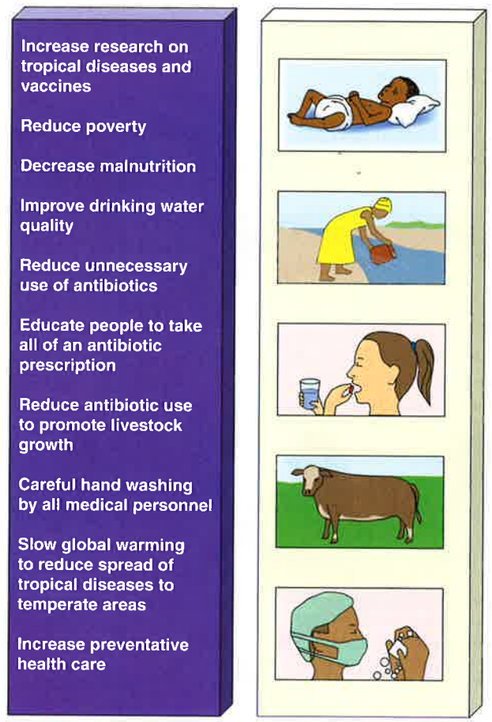

Figure 16-12 Solutions. Ways to prevent or reduce the incidence of infectious diseases.

16-5 RISK ANALYSIS

How Can We Estimate Risks? Risk analysis involves **(1)** identifying hazards and evaluating their associated risks (*risk assessment*, Figure 16-2, left), **(2)** ranking risks (*comparative risk analysis*), **(3)** determining options and making decisions about reducing or eliminating risks (*risk management*, Figure 16-2, right), and **(4)** informing decision makers and the public about risks (*risk communication*).

Statistical probabilities based on past experience, animal testing and other tests, and epidemiological studies are used to estimate risks from older technologies and chemicals (Section 16-1). To evaluate new technologies and products, risk evaluators use more uncertain statistical probabilities, based on models rather than actual experience.

The left side of Figure 16-13 is an example of *comparative risk analysis*, summarizing the greatest ecological and health risks identified by a panel of scientists acting as advisers to the U.S. Environmental Protection Agency. Note the difference between the comparison of relative risk by scientists (Figure 16-13, left) and the general public (Figure 16-13, right). These differences result largely from failure of professional risk evaluators to communicate the nature of risks and their relative importance to the public, teachers, and members of the media. Some risk experts contend that much of our risk education is based on often misleading media reports on the latest risk scare of the week (based mainly on frontier science) that do not put such risks in perspective.

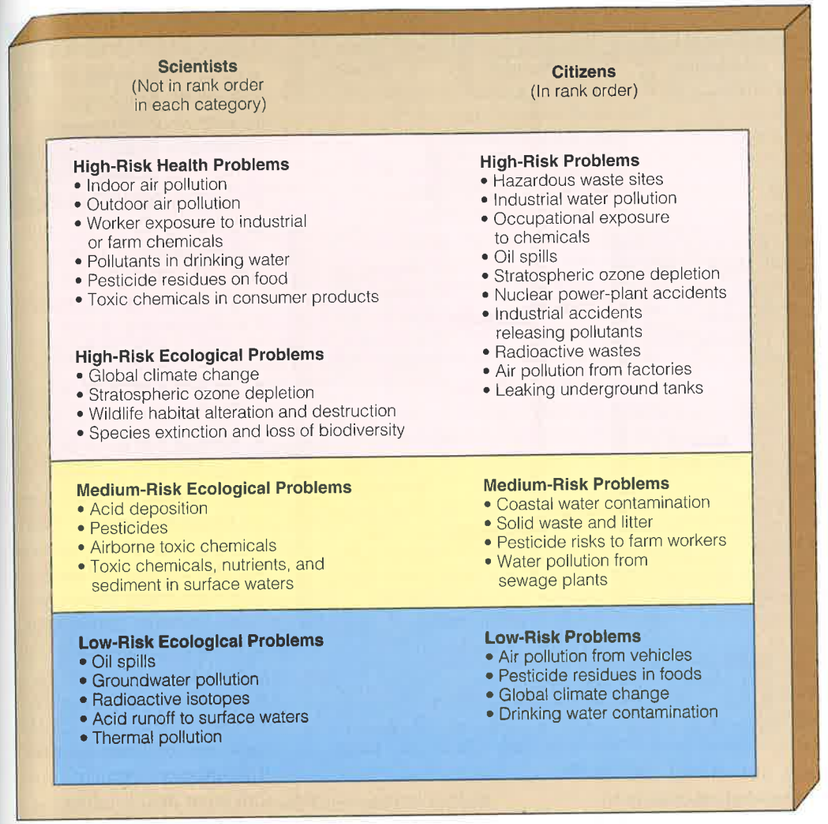

Figure 16-13 Comparative risk analysis of the most serious ecological and health problems according to scientists acting as advisers to the U.S. Environmental Protection Agency (left column). Risks in each of these categories are not listed in rank order. The right side of this figure represents polls showing how U.S. citizens rank the ecological and health risks they perceive as being the most serious. Why do you think there is such a great difference between the ranking by risk experts and by the general public? (Data from Science Advisory Board, *Reducing Risks*, Washington, D.C.: Environmental Protection Agency, 1990)

Once a risk assessment has been completed, decision makers much decide what level of risk is acceptable. Figure 16-14 shows four methods used to determine the acceptability of a risk. The most widely used method is *cost-benefit analysis*, which attempts to determine whether the estimated short- and long-term risks or costs of using a particular technology or chemical outweigh its the estimated short- and long-term benefits.

What Are the Greatest Risks People Face? The greatest risks many people face today are rarely dramatic enough to make the daily news. In terms of reduced life span from malnutrition, exposure to disease-causing organisms and dangerous chemicals, and lack of basic health care, *the greatest risk by far is poverty* (Figure 16-15, p. 414).

After the health risks associated with poverty, the greatest risks of premature death are mostly the result of voluntary choices people make about their lifestyles (Figures 16-1 and 16-15).

By far the best ways to reduce one's risk of premature death and serious health risks are to **(1)** not smoke, **(2)** avoid excess sunlight (which ages skin and causes skin cancer), **(3)** not drink alcohol or drink only in moderation (no more than two drinks in a single day), **(4)** reduce consumption of foods containing cholesterol and saturated fats, **(5)** eat a variety of fruits and vegetables, **(6)** exercise regularly, **(7)** lose excess weight, and **(8)** for those who can afford a car, drive as safely as possible in a vehicle with the best available safety equipment.

However, we have little or no control over some factors that can influence our vulnerability to some risks. For example, we cannot control **(1)** our gender, **(2)** the genes we inherited from our parents, and **(3)** our social and psychological environment during early childhood.

How Can We Estimate Risks for Technological Systems? The more complex a technological system and the more people needed to design and run it, the more difficult it is to estimate the risks. The overall reliability of any technological system (expressed as a percentage) is the product of two factors:

System reliability (%) = Technology reliability × Human reliability

With careful design, quality control, maintenance, and monitoring, a highly complex system such as a nuclear power plant or space shuttle can achieve a high degree of technology reliability. However, human reliability usually is much lower than technology reliability and is almost impossible to predict: To err is human.

Suppose that the technology reliability of a nuclear power plant is 95% (0.95) and that human reliability is 75% (0.75). Then the overall system reliability is 71% ($0.95 \times 0.75 = 0.71 = 71\%$). Even if we could make the technology 100% reliable (1.0), the overall system reliability would still be only 75% ($1.0 \times 0.75 = 0.75 = 75\%$). The crucial dependence of even the most carefully designed systems on unpredictable human reliability helps explain essentially "impossible" tragedies such as the Chernobyl (p. 350) nuclear power-plant accident and the explosion of the space shuttle *Challenger*.

One way to make a system more foolproof or fail-safe is to move more of the potentially fallible elements from the human side to the technical side. However, **(1)** chance events such as a lightning bolt can knock out automatic control system, **(2)** no machine or computer program can completely replace human judgment, **(3)** the parts in any automated control system are manufactured, assembled, tested, certified, and maintained by fallible human beings, and **(4)** computer software programs used to monitor and control complex systems can also contain human error or can be deliberately modified by computer viruses to malfunction.

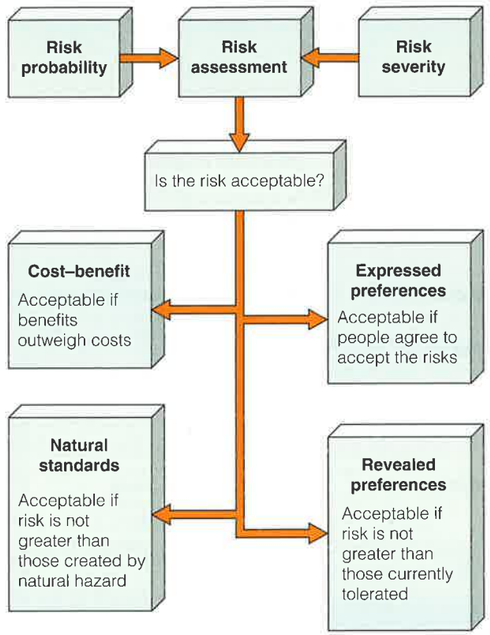

Figure 16-14 Methods for determining the acceptability of a risk after a risk assessment has been made. Cost–benefit analysis is the most widely used method. (Adapted from *Environmental Science*, 5/E by Chiras, p. 351. Copyright ©1998 by Wadsworth)

What Are the Limitations of Risk Analysis? Here are some of the key questions involved in evaluating risk analysis:

- How reliable are risk assessment data and models?
- Who profits from allowing certain levels of harmful chemicals into the environment, and who suffers? Who decides this?
- Should estimates emphasize short-term risks, or should more weight be put on long-term risks? Who should make this decision?
- Should the primary goal of risk analysis be to determine how much risk is acceptable (the current approach) or to figure out how to do the least damage (a prevention approach)?
- Who should do a particular risk analysis, and who should review the results? A government agency? Independent scientists? The public?
- Should cumulative effects of various risks be considered, or should risks be considered separately, as is usually done? Suppose a pesticide is found to have an annual risk of killing 1 person in 1 million from cancer, the current EPA limit. Cumulatively, however, effects from 40 such pesticides might kill 40, or 400, of every 1 million people. Is this acceptable and to whom?
- How widespread is each risk?
- Should risk levels be higher for workers (as is almost always the case) than for the general public? What say should workers and their families have in this decision? According to government estimates, the exposure of workers to toxic chemicals in the United States causes 50,000–70,000 deaths (at least half from cancer) and 350,000 new cases of illness per year. The situation is much worse in developing countries, with more than 1 million work-related deaths occurring worldwide each year. Is this a necessary cost of doing business?
- How much risk is acceptable and to whom? According to the National Academy of Sciences, exposure to toxic chemicals is responsible for 2–4% of the 521,000 cancer deaths in the United States; this amounts to 10,400–20,800 premature cancer deaths per year. Is this acceptable or unacceptable and to whom?

Proponents contend that risk analysis is a useful way to **(1)** organize and analyze available scientific information, **(2)** identify significant hazards, **(3)** focus on areas that warrant more research, **(4)** help regulators decide how money for reducing risks should be allocated, and **(5)** stimulate people to make more informed decisions about health and environmental goals and priorities.

However, critics point out that results of risk analysis are very uncertain. For example, a recent study documented the significant uncertainties involved in even simple risk analysis. Eleven European governments established 11 different teams of their best scientists and engineers (including those from private companies) to assess the hazards and risks from a small plant storing only one hazardous chemical (ammonia). The 11 teams, consisting of world-class experts analyzing this very simple system, disagreed with one another on fundamental points and varied in their assessments of the hazards by a factor of 25,000.

Such built-in uncertainty in risk analysis is analogous to a radar device that can detect a car speeding at 160 kilometers (100 miles) per hour but can tell us only that the car is traveling somewhere between 0.16 kilometer (0.1 mile) per hour and 160,000 kilometers (100,000 miles) per hour. Such inherent uncertainty explains why regulators setting human exposure levels for toxic substances usually divide the best results by 100 to 1,000 to provide the public with a margin of safety.

According to critics, the main decision-making tool we should rely on is not to find out how much risk is acceptable—which is mostly a political question. Instead, it should be to find out the least damaging reasonable alternatives by asking, "Which alternative will bring sufficient benefits and minimize damage to humans and to the earth?" In other words, the emphasis should be on *alternative assessment* not *risk assessment*.

How Should Risks Be Managed? **Risk management** includes the administrative, political, and economic actions taken to decide whether and how to reduce a particular societal risk to a certain level and at what cost.

Risk management involves deciding:

- The reliability of the risk analysis for each risk.
- Which risks should be given the highest priority.
- How much risk is acceptable (Figure 16-14).
- How much it will cost to reduce each risk to an acceptable level.
- How limited funds should be spent to provide the greatest benefit.
- How the risk management plan will be monitored, enforced, and communicated to the public.

Each step in this process involves making value judgments and weighing trade-offs to find some reasonable compromise among conflicting political, economic, health, and environmental interests.

How Well Do We Perceive Risks? How much risk is acceptable? Studies indicate that if the chance of death from a chemical or activity is less than 1 in 100,000, most people are not likely to be worried enough to change their ways.

However, most of us do poorly in assessing the relative risks from the hazards that surround us (Figure 16-13 and 16-15). Also, many people deny or shrug off

Improving Health Care in Developing Countries

SOLUTIONS

With adequate funding, the health of people in developing countries and the poor in developed countries can be improved dramatically, quickly, and cheaply by providing the following forms of mostly preventive health care:

- Better nutrition, prenatal care, and birth assistance for pregnant women. At least 585,000 women in developing countries die each year of mostly preventable causes related to pregnancy and childbirth, compared with about 6,000 in developed countries. According to the World Health Organization, the majority of these deaths in low-income countries could be prevented for as little as $2 per woman per year.
- Better nutrition for children.
- Greatly improved postnatal care (including promotion of breast-feeding) to reduce infant mortality. Breast-fed babies get natural immunity to many diseases from antibodies in their mothers' milk.
- Immunization against the world's five largest preventable infectious diseases: tetanus, measles, diphtheria, typhoid fever, and polio. Since 1971 the percentage of children in developing countries immunized against these diseases has increased from 10% to 84%, saving about 10 million lives a year.
- Oral rehydration therapy for victims of diarrheal diseases, which cause about one-fourth of all deaths of children under age 5. A simple solution of boiled water, salt, and sugar or rice, at a cost of only a few cents per person, can prevent death from dehydration. According to the British medical journal *Lancet*, this simple treatment is "the most important medical advance of the 20th century."
- Careful and selective use of antibiotics for infections (Spotlight, p. 406).
- Clean drinking water and sanitation facilities for the one-third of the world's population that lacks them.

According to the World Health Organization, extending such primary health care to all the world's people would cost an additional $10 billion per year, about 4% of what the world spends every year on cigarettes or devotes every 4 days to military spending. The cost of this program is about $1 per child.

Critical Thinking

1. Do you believe that developed countries should foot at least half the bill for implementing such proposals? What economic and environmental benefits would this provide for developed countries?

2. How many dollars per year of your taxes would you be willing to spend for such a preventive health program in developing countries?

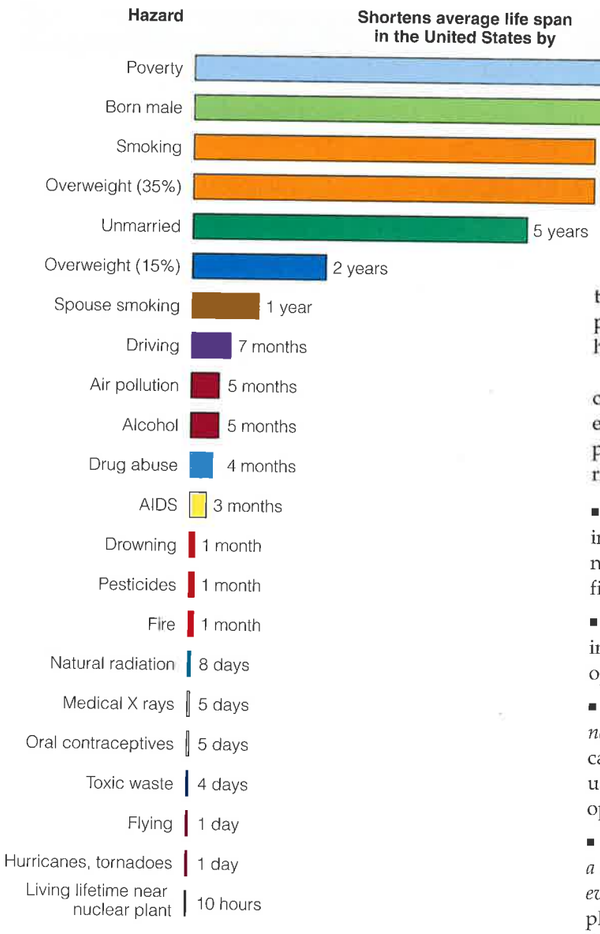

Figure 16-15 Comparison of risks people face, expressed in terms of shorter average life span. After poverty, the greatest risks people face result mostly from voluntary choices they make about their lifestyles. These are only generalized relative estimates. Individual response to some of these risks can vary with factors such as **(1)** genetic variation (Figure 16-3), **(2)** family medical history, **(3)** emotional makeup, **(4)** stress, and **(5)** social ties and support. (Data from Bernard L. Cohen)

the high-risk chances of dying (or injury) from voluntary activities they enjoy, such as **(1)** motorcycling (1 death in 50 participants), **(2)** smoking (1 in 300 participants by age 65 for a pack-a-day smoker), **(3)** hang-gliding (1 in 1,250), and **(4)** driving (1 in 2,500 without a seatbelt and 1 in 5,000 with a seatbelt).

Yet some of these same people may be terrified about the possibility of dying from a **(1)** commercial airplane crash (1 in 4.6 million), **(2)** train crash (1 in 20 million), **(3)** snakebite (1 in 36 million), **(4)** shark attack (1 in 300 million), or **(5)** exposure to trichloroethylene (TCE) in drinking water at the trace levels allowed by the EPA (1 in 2 billion).

Being bombarded with news about people killed or harmed by various hazards distorts our sense of risk. However, *the most important good news each year is that about 99.1% of the people on the earth did not die.* Despite the greatly increased use of synthetic chemicals in food production and processing, the general health and average life expectancy of people in the United States (and most developed countries) have increased during the past 50 years.

Our perceptions of risk and our responses to perceived risks often have little to do with how risky the experts say something is (Figures 16-13 and 16-15). The public generally sees a technology or a product as being riskier than experts do when:

- *It is new or complex rather than familiar.* Examples include genetic engineering (Pro/Con, p. 275) or nuclear power, as opposed to large dams or coal-fired power plants (Figure 14-36, p. 349).
- *It is perceived as being mostly involuntary.* Examples include nuclear power plants or food additives, as opposed to driving or smoking.
- *It is viewed as unnecessary rather than as beneficial or necessary.* Examples might include using chlorofluorocarbon (CFC) propellants in aerosol spray cans or using food additives that increase sales appeal, as opposed to cars or aspirin.
- *Its use involves a large, well-publicized death toll from a single catastrophic accident rather than the same or an even larger death toll spread out over a longer time.* Examples might include a severe nuclear power plant accident (p. 350), an industrial explosion, or a plane crash, as opposed to coal-burning power plants, automobiles, or smoking.
- *Its use involves unfair distribution of the risks.* Citizens are outraged when government officials decide to put a hazardous-waste landfill or incinerator in or near their neighborhood, even when the decision is based on risk analysis. This is usually seen as politics, not science. Residents will not be satisfied by estimates that the lifetime risks of cancer death from the facility are not greater than, say, 1 in 100,000. Living near the facility means that they, not the 99,999 people living farther away, have a much higher risk of dying from cancer by having this risk involuntarily imposed on them.
- *The people affected are not involved in the decision-making process from start to finish.*
- *Its use does not involve a sincere search for and evaluation of alternatives.* People who believe that their lives and the lives of their families are being threatened want to know what the alternatives are and which alternative causes the least harm to them and the earth.

Better education and communication about the nature of risks will help bring the public's perceptions of various risks closer to those of professional risk evaluators. However, such education will not eliminate the emotional, cultural, and ethical factors that decision makers must take into account in determining the acceptability of a particular risk and evaluating the possible alternatives.

The burden of proof imposed on individuals, companies, and institutions should be to show that pollution prevention options have been thoroughly examined, evaluated, and used before lesser options are chosen.

JOEL HIRSCHORN

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.
2. What human activity kills the largest number of people each year? List six ways to help reduce the harmful effects of smoking.
3. What are *risk* and *probability*? Distinguish between *risk assessment* and *risk management*.
4. List two **(a)** cultural hazards, **(b)** chemical hazards, **(c)** physical hazards, and **(d)** biological hazards.
5. What is *toxicity*? Distinguish between *dosage* and *response* for a potentially harmful substance. List five factors that determine whether a chemical is harmful. Distinguish between *bioaccumulation* and *biomagnification*. List three mechanisms by which the human body can reduce the harmful effects of most harmful chemicals.
6. What is a *poison*? What is an LD_{50}? List three methods used to determine toxicity and list the limitations of each method. Describe how laboratory tests are used to determine toxicity. What is a *dose–response curve*? Distinguish between a *linear dose–response curve* and a *threshold dose–response curve*.
7. Distinguish between *toxic chemicals* and *hazardous chemicals*. Distinguish between *mutagens*, *teratogens*, and *carcinogens* and give one example of each.
8. Distinguish between the *immune system*, *nervous system*, and *endocrine system* and give an example of something that causes harm to each system. What are *hormone disrupters* and *hormone mimics*? List two examples of such chemicals.
9. About what percentage of the 75,000 chemicals in commercial use in the United States have been screened **(a)** to assess toxicity, **(b)** to determine whether they are carcinogens, teratogens, or mutagens, and **(c)** to determine whether they damage the nervous, endocrine, or immune systems? What percentage of the commercially used chemicals in the United States do federal and state governments regulate?
10. List three reasons for the lack of information about the potentially harmful effects of most chemicals in commercial use. Distinguish between the regulation strategy and the pollution prevention strategy for protecting the public from potentially harmful chemicals. What is the *precautionary principle*? Why is it rarely used?
11. Distinguish between *nontransmissible* and *transmissible diseases* and give two examples of each type. About how many children die each year in developing countries from mostly preventable infectious diseases? What are the seven deadliest infectious diseases in order of the number of deaths they cause each year?
12. What are the major types of diseases in **(a)** developing countries, **(b)** developed countries, and **(c)** the United States? What is an *epidemiologic transition*?
13. How do infectious bacteria become resistant to antibiotics? List seven factors that have led to an increase in infectious diseases that cannot be controlled by most antibiotics.
14. What is the best way to treat **(a)** a bacterial disease and **(b)** a viral disease? List two examples of each type of disease.
15. What causes tuberculosis, and how is it transmitted? About how many people died from TB during the past year? List five reasons for the increase in TB infections in recent years. How can the spread of this bacterial infectious disease be slowed?
16. Distinguish between *HIV* and *AIDS*. List four ways in which HIV can be transmitted. About how many people in the world are **(a)** infected with HIV and **(b)** have died of AIDS? During the past year, about how many people were infected with HIV and how many people died of AIDS? List ways to prevent the spread of this viral infectious disease.
17. List 10 factors that can affect the spread of infectious diseases.
18. What causes malaria? About how many people die from malaria each year? List six ways to help prevent this protozoal infectious disease.
19. List 10 ways to prevent or reduce the incidence of infectious diseases throughout the world. List seven major ways to improve health care in developing countries. About how much would implementing these measures cost per year?
20. What is *risk analysis*? What are the major limitations of risk analysis?
21. List five of the greatest risks people face in terms of reduced life span. List eight ways to reduce your risk of premature death and serious health problems. How can we estimate the risks from technological systems?
22. What is *risk management*? What six questions do risk managers try to answer? About what percentage of the people on the earth die each year? List seven reasons that lead people to perceive that certain risks are greater than experts say they are.

CRITICAL THINKING

1. Explain why you agree or disagree with the proposals made by health officials for reducing the death toll and other harmful effects of smoking listed on p. 396.

2. Do you think chemicals should be regulated based on their effects on the nervous, immune, and endocrine systems? Explain.

3. Should we have zero pollution levels for all hazardous chemicals? Explain.

4. Do you believe that health and safety standards in the workplace should be strengthened and enforced more vigorously, even if this causes a loss of jobs when companies transfer operations to countries with weaker standards? Explain.

5. Evaluate the following statements:
- **a.** We should not get so worked up about exposure to toxic chemicals because almost any chemical can cause some harm at a large enough dosage.
- **b.** We should not worry so much about exposure to toxic chemicals because through genetic adaptation we can develop immunity to such chemicals.
- **c.** We should not worry so much about exposure to toxic chemicals because we can use genetic engineering to reduce or eliminate such problems.

6. How can changes in the age structure of a human population increase the spread of infectious diseases? How can the spread of infectious diseases affect the age structure of human populations?

7. Should pollution levels be set to protect the most sensitive people in a population (Figure 16-3, left) or the average person (Figure 16-3, middle)? Explain.

8. What are the five major risks you face from your lifestyle, where you live, and what you do for a living? Which of these risks are voluntary and which are involuntary? List the five most important things you can do to reduce these risks. Which of these things do you actually plan to do?

9. How would you answer each of the questions raised about **(a)** risk analysis on p. 412, and **(b)** risk assessment and risk management on p. 413? Explain each of your answers.

PROJECTS

1. Assume that members of your class (or small manageable groups in your class) have been appointed to a technology risk-benefit assessment board. As a group, decide why you would approve or disapprove of widespread use of each of the following: **(a)** drugs to retard aging, **(b)** electrical or chemical devices that would stimulate the brain to eliminate anxiety, fear, unhappiness, and aggression, and **(c)** genetic engineering to produce people with superior intelligence and strength.

2. Use the library or the internet to find recent articles describing the rise of genetic resistance of disease-causing bacteria to commonly used antibiotics. Evaluate the evidence and claims in these articles.

3. Pick a specific viral disease and use the library or internet to find out about **(a)** how it spreads, **(b)** its effects, **(c)** strategies for controlling its spread, and **(d)** possible treatments.

4. Use the library or the internet to find bibliographic information about *Paracelsus* and *Joel Hirschorn*, whose quotes appear at the beginning and end of this chapter.

5. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look at the inside back cover and on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to:

http://www.brookscole.com/product/0534376975s

and click on the Chapter-by-Chapter area. Choose Chapter 16 and select a resource:

- "Flash Cards" allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- "Tutorial Quizzes" provides a multiple-choice practice quiz.
- "Student Guide to InfoTrac" will lead you to Critical Thinking Projects that use InfoTrac College Edition as a research tool.
- "References" lists the major books and articles consulted in writing this chapter.
- "Hypercontents" takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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Try the following articles:

Gregory, R. 2000. Using stakeholder values to make smarter environmental decisions. *Environment* vol. 42, no. 5, pp. 34–41. (subject guide: risk assessment)

Hunter, B.T. 2000. New alternatives in safety testing: testing product safety without using animals. *Consumers' Research Magazine* vol. 83, no. 5, pp. 26–30. (toxicology, technique)

17 AIR AND AIR POLLUTION

When Is a Lichen Like a Canary?

Nineteenth-century coal miners took canaries with them into the mines—not for their songs, but for the moment when they stopped singing. Then the miners knew it was time to get out of the mine because the air contained methane, which could ignite and explode.

Today we use sophisticated equipment to monitor air quality, but living things such as lichens (Figure 17-1) still can warn us of bad air. A lichen consists of a fungus and an alga living together, usually in a mutually beneficial (mutualistic) partnership.

These hearty pioneer species are good air pollution detectors because they are always absorbing air as a source of nourishment. Certain lichen species are sensitive to specific air-polluting chemicals. Old man's beard (*Usnea trichodea*) (Figure 17-1, right) and yellow *Evernia* lichens, for example, sicken or die in the presence of too much sulfur dioxide.

Because lichens are widespread, long-lived, and anchored in place, they can also help track pollution to its source. The scientist who discovered sulfur dioxide pollution on Isle Royale in Lake Superior (Case Study, p. 204), where no car or smokestack had ever intruded, used *Evernia* lichens to point the finger northward to coal-burning facilities at Thunder Bay, Canada.

Radioactive particles spewed into the atmosphere by the Chernobyl nuclear power-plant disaster (p. 350) fell to the ground over much of northern Scandinavia and were absorbed by lichens that carpet much of Lapland. The area's Saami people depend on reindeer meat for food, and the reindeer feed on lichens. After Chernobyl more than 70,000 reindeer had to be killed and the meat discarded because it was too radioactive to eat. Scientists helped the Saami identify which of the remaining reindeer to move by analyzing lichens (which absorbed some of the radioactive fallout) to pinpoint the most contaminated areas.

Last but not least, lichens can replace electronic monitoring stations that cost more than $100,000 each. This is not so much a triumph of nature over technology as a partnership between the two, for technicians use highly sophisticated methods to analyze lichens for pollution and measure their rates of photosynthesis.

We all must breathe air from a global atmospheric commons in which air currents and winds can transport some pollutants long distances. Thus, air pollution anywhere is a potential threat elsewhere. Lichens can alert us to the danger, but as with all forms of pollution, the best solution is prevention.

Figure 17-1 Red and yellow crustose lichens growing on slate rock in the foothills of the Sierra Nevada near Merced, California (left), and *Usnea trichodea* lichen growing on a branch of a larch tree in Gifford Pinchot National Park, Washington (right). The vulnerability of various lichen species to specific air pollutants can help researchers detect levels of these pollutants and track down their sources. (Left, Kenneth W. Fink/Ardea, London; right, Milton Rand/Tom Stack & Associates)